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EXPLORATORY LOADING TECHNIQUES

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FINAL REPORT

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EXPLORATORY LOADING TECHNIQUES IN HOLOGRAPHIC NON-DESTRUCTIVE TESTING

Abstract

The loading techniques of positive pressure, negative pressure, heating, and cooling have been applied to several flat metal plates. Several different types of structural weaknesses are simulated in the study.

I. Introduction

The purpose of this study was to develop and investigate "Holographic Non-Destructive Testing", (HNDT) loading techniques. The ultimate aim of this study is to be able to predict the best loading technique as a function of flaw type and kind and thickness of material. The loading techniques included in this investigation were positive pressure, negative pressure (vacuum), cooling and heating. The interferometric techniques known as double exposure and real-time interferometry were both applied in this study.

II. Interferometric Theory

A. Double Exposures

Holography permits a rather unique extension of classical interferometry, used to measure small optical path-length differences of two phase related wave fronts. The technique popularly known as interferometric holography was first reported by Powell and Stetson.[1] This technique is similar to conventional holography except two exposures are recorded on the same photographic plate. In between exposures the object is "loaded" in some manner. Upon reconstructing the

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[1] R. Powell and K. Stetson, "Interferometric Vibration Analysis by Wave Front Reconstruction", J. Opt. Soc. Am. 55, 1593 (1965).

hologram, two three-dimensional images of the object will be formed. Both reconstructed images exist in the same general spatial location and they will interfere with each other because of the coherence property of the laser light. The result of this interference between the two images is a set of bright and dark interference fringes superimposed on the images. These fringes represent contours of equal displacement along the viewing axis. Each successive fringe represents a displacement of approximately one-half the wavelength of the coherent light source used in the construction process.

B. Real-Time Method

This technique requires taking a single holographic exposure of an object, processing the film and replacing it in exactly the same position in which it was recorded. This precision placing must be within the order of wavelengths of the laser light used. The hologram is then reconstructed with the original coherent reference beam. The result is the reconstructed image now superimposed onto the original object, which is also illuminated with the same light as when the hologram was recorded. Interference fringes can then be seen as the surface of the object is displaced from its original location. This interferometric comparison between the original state of the object and its new state is made at the instant it occurs (i. e., "real-time"). An obvious advantage of this technique is that many different types of motions can be studied with a single holographic exposure.

C. Interferometric HNDT

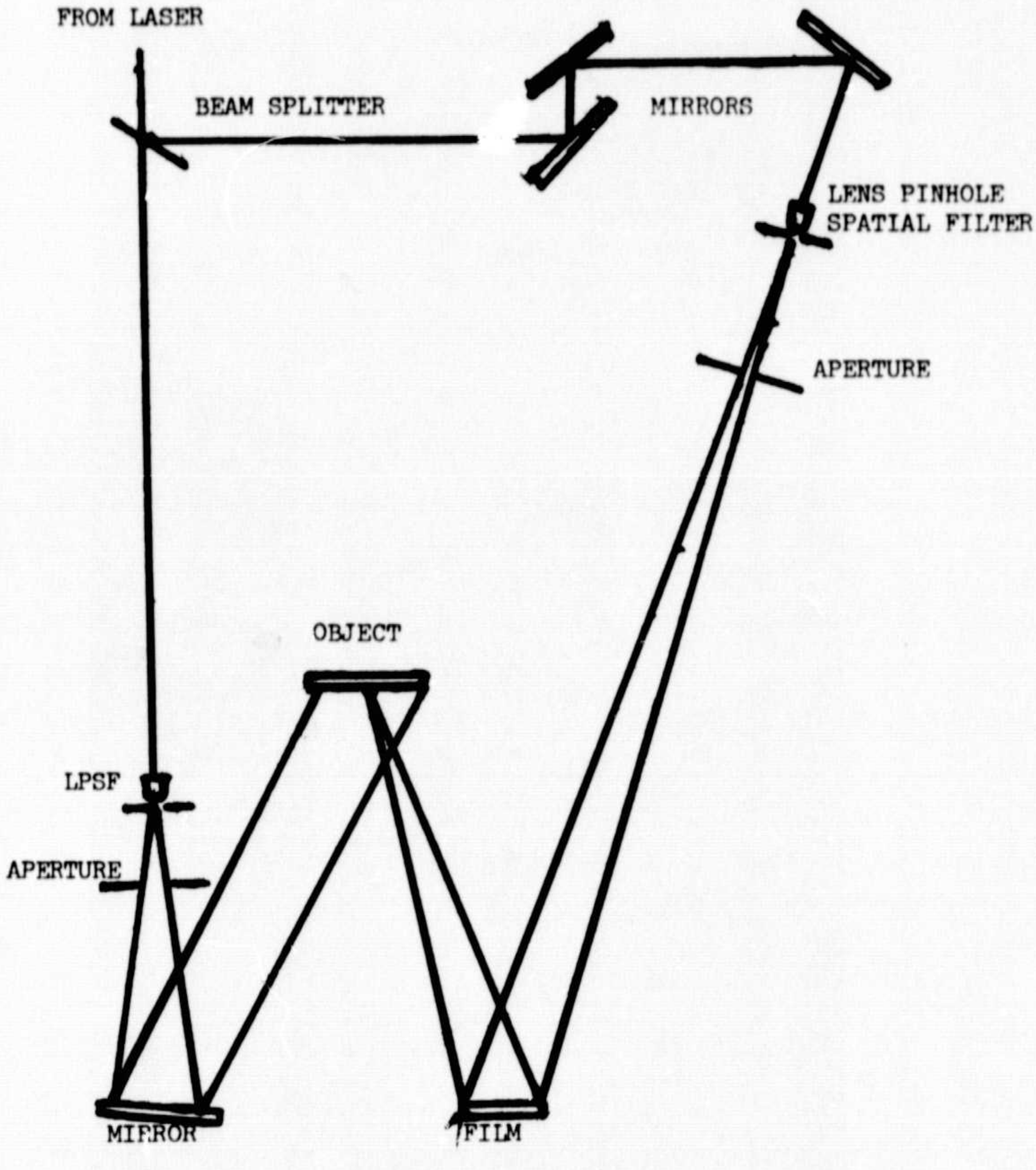
Interferometric holography permits the detection and measurement of changes in the surface shape of an object by providing a process for the comparison of each point on the surface with itself before and after a change takes place. This technique, with its extreme sensitivity, can be used to gain meaningful information with regard to the structural characteristics of a component by observing the fringe patterns when the component is subjected to a mild stress. Thus it offers the potential for many inspection problems where the defect of interest can be made manifest as an anomaly in the otherwise regular interferometric fringe pattern.

III. Experimental Apparatus

The holographic system is shown in Figure 1. Note the film plane is parallel to the flat object plane and the angle of incidence on the film plane is approximately the same for object beam and reference beam.

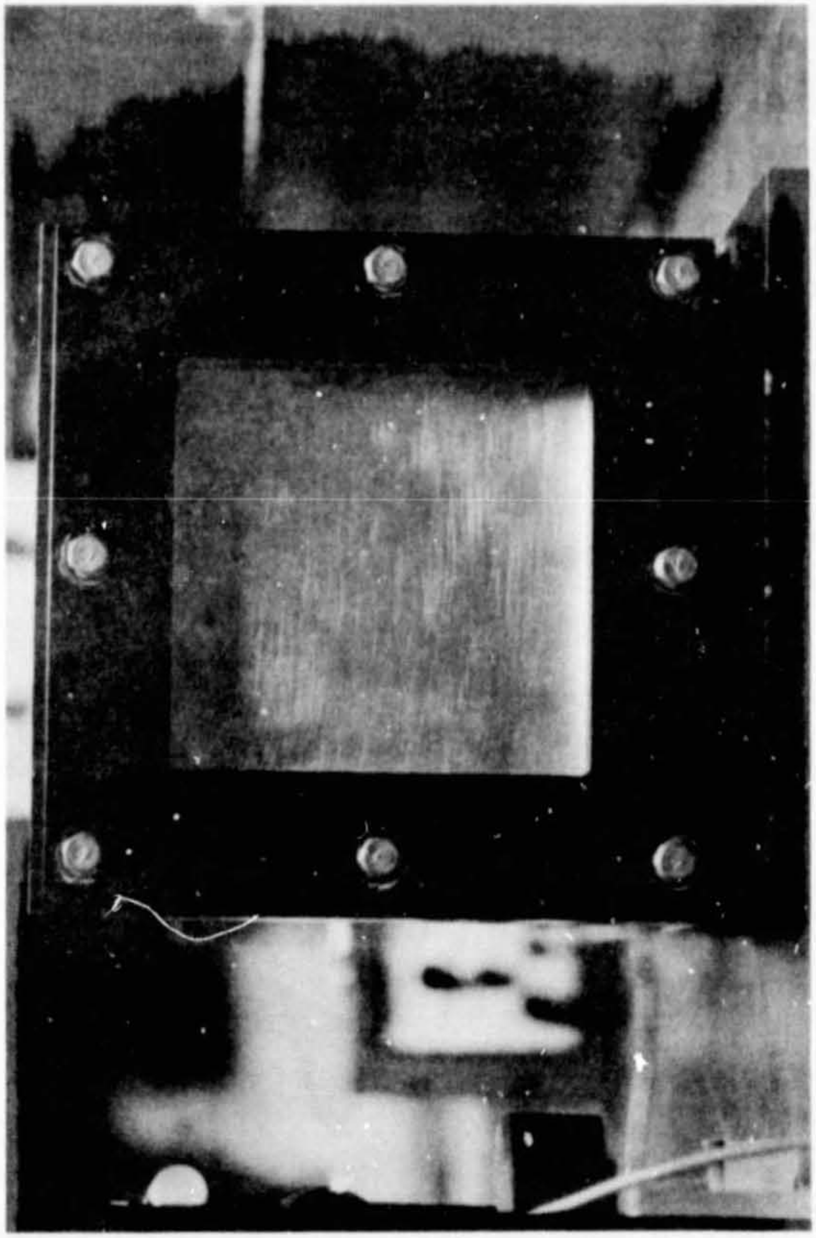
The samples that were to be tested in this study were flat sheets two inches square. It was soon determined that these samples were too small to work with conveniently. Therefore, a larger holder was developed and built to accept flat sheets seven and one-half inches square. A picture of this holder is shown in Figure 2. The holder provides a cavity behind the flat plates which can be pressurized through the rear of the holder. It was designed to operate with a positive pressure

FIGURE 1. THE HOLOGRAPHIC SYSTEM



SCALE 1/10 TH ACTUAL

FIGURE 2. THE SAMPLE HOLDER



or vacuum in this cavity. An accurate measure of pressure changes was accomplished by employing a strain gauge pressure transducer. This system is capable of measuring pressure changes to within 0.0167 p. s. i.

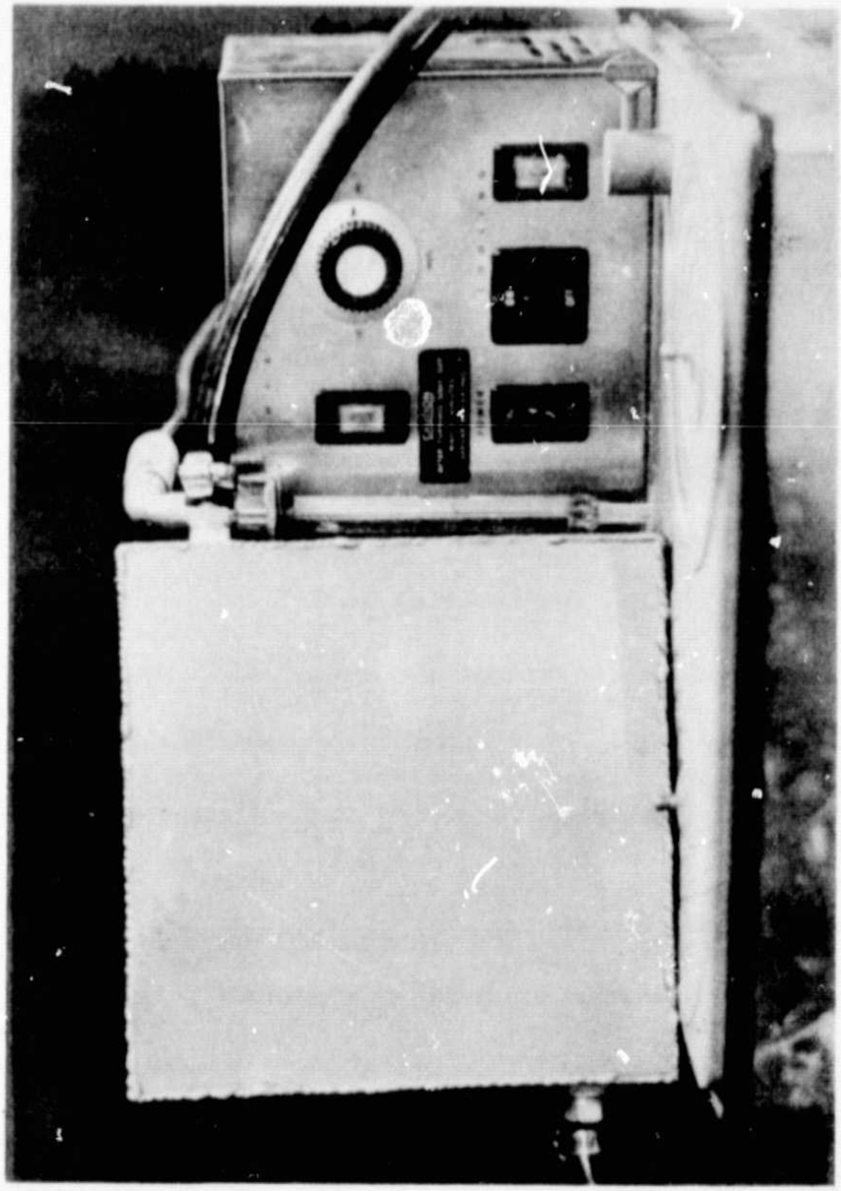
Temperature control was accomplished by placing a circulation vessel behind the sample and inside the aforementioned sample holder. This vessel is shown in Figure 3. Temperature controlled water was circulated through this vessel. The controller is a Precision Scientific "Lo Temptrol 154". The temperature attained by the samples was accurately monitored using a quartz thermometer "Dymec Model 2800A" which reads to the nearest tenth of a degree Centigrade.

The real-time experiments were documented with 35 mm pictures of the virtual image, the results of which are presented in this report. This procedure represents a considerable cost savings over the double exposure technique. Additionally some of the work has been documented using a video tape recording of the virtual image.

IV. Experimental Procedure

The samples tested consisted of various thicknesses of copper, aluminum, steel and brass. These are materials representative of space industry structures. The flaws investigated were radical structural flaws that might be found to a lesser degree in actual space products and structures. These flaws were as follows:

FIGURE 3. THE TEMPERATURE CONTROL VESSEL



A. A hole milled half-way through the sample from the rear, located 1.75 inches from center along the diagonal in quadrant I. The diameters of the holes included were one-eighth and one-quarter inch.

B. A horizontal groove centered on the plate. The groove as milled in the rear having dimensions four by one-quarter or one-eighth inch by half the thickness of the material.

C. Tape was rolled and placed near the center of quadrant I (in the rear). The thickness of the roll was such as to cause stress in the plate as it was placed in the holder.

Vacuum and positive pressure produced virtually indistinguishable results as shown in Figure 4. Consequently, only positive pressure was applied in detail.

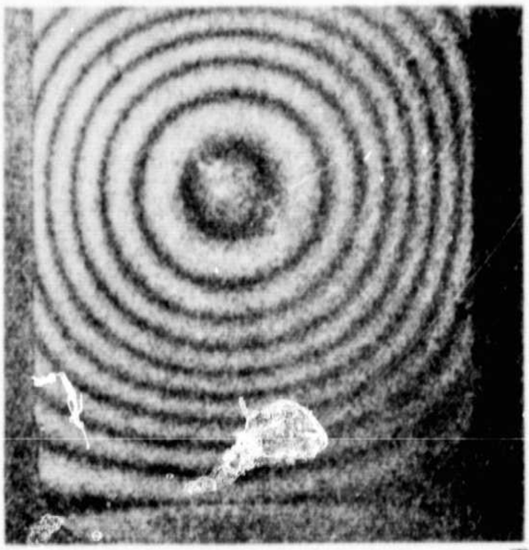
Initial pressure loading was used with "real-time" interferometry which produced unexpected results. The quarter inch hole, described above, was not revealed in the thin aluminum sample. However, after the real-time was allowed to remain overnight the hole became evident. The cause may be attributed to temperature stress as the room got quite cool overnight. This conclusion is strengthened by causing this to occur in a "fresh" real-time by heating the sample with a heat lamp. Further probing into this technique led to the following

FIGURE 4. POSITIVE AND NEGATIVE PRESSURE COMPARED

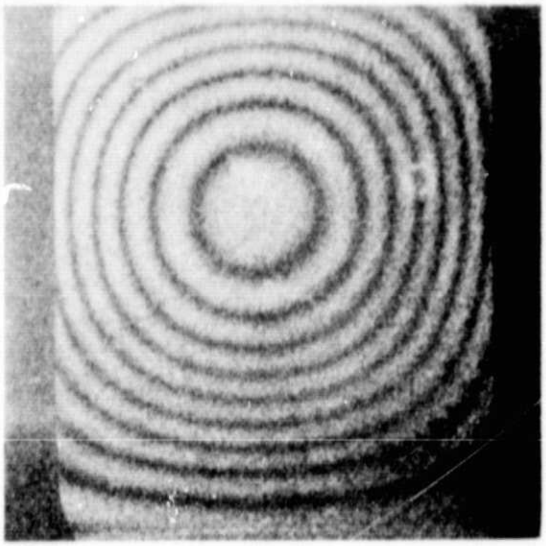
Reference Pictures

$\Delta P = 1.5$ p. s. i.

Vacuum



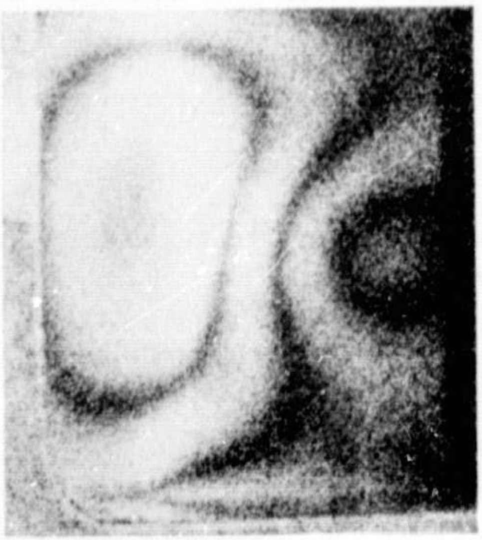
Positive



Tape Roll

$\Delta P = 1.0$ p. s. i.

Vacuum



Positive

conclusions:

1. Best results were obtained when the pressure was very near reference (i.e., very little change in pressure).
2. The flaws were easier to detect in samples that were thinnest. This is likely because the thin samples receive and reject their heat more rapidly (i.e., they have a lower heat capacity).

Double exposure interferometry was applied, but repeatability was unsatisfactory. This may be attributed to the necessity for rapidly changing temperature which makes the proper conditions difficult to capture in a single double exposure. In the real-time work the proper conditions can be observed and photographed. Because of these difficulties with double exposures and because they are considerably more expensive to implement, most of the work was done with the real-time technique.

Pure temperature loading was not very successful for the following reasons:

1. Because it was necessary to insulate the samples from their surroundings it was not possible to totally prevent the sample from slipping (i.e., metal to metal clamping was not used).

2. The vertical plate configuration radiates non-uniformly.

3. The thickest samples were more difficult to constrain because of their larger absolute expansion with heating. Also these samples do not change temperature as rapidly as necessary to detect flaws.

4. The non-uniformity of the fringe patterns (as illustrated in Figure 5) in the reference pictures make it difficult to detect irregularities produced by prescribed flaws.

As documented in video tape, but not in this report, this loading technique failed to expose the one-quarter inch diameter hole which was easily seen by techniques described earlier in real-time work. Consequently, the temperature controlling vessel was not employed further.

The photographic evidence of these prescribed flaws is presented in Figures 6 - 8. Figure 6 shows the three thicknesses of aluminum in increasing size from left to right. In the first line each photograph clearly exposes the presence of the quarter inch hole in quadrant I. This effect is not as good in the thickest sample. The next line shows the results with the one-eighth inch hole where the

absence of the third photograph indicates the inability to expose this size hole in this thickness plate. The next two lines of photographs clearly exhibit the presence of the quarter inch and eighth inch groove. Perhaps the one-eighth inch groove in the thickest sample is least prominent. The last line of photographs exhibit the presence of the compressed tape in quadrant I and clearly the thickest sample gives only subtle evidence of the tape.

Figure 7 illustrates some of the results with the copper sample. Only the quarter inch groove was exposed in the thicker copper plate. There is shown some very subtle evidence of the tape. The remaining pictures for the holes and one-eighth inch groove in the thicker copper were indistinguishable from reference pictures and have not been included.

Figure 8 shows the results with the steel samples. The first line clearly exposes the quarter inch hole in quadrant I. The second line exhibits the presence of the one-eighth inch hole in the thinnest sample. The next two lines clearly exhibit the presence of the horizontal grooves in both samples. The last line shows the evidence of the compressed rolls of tape in quadrant I for each sample.

FIGURE 5. TEMPERATURE LOADING

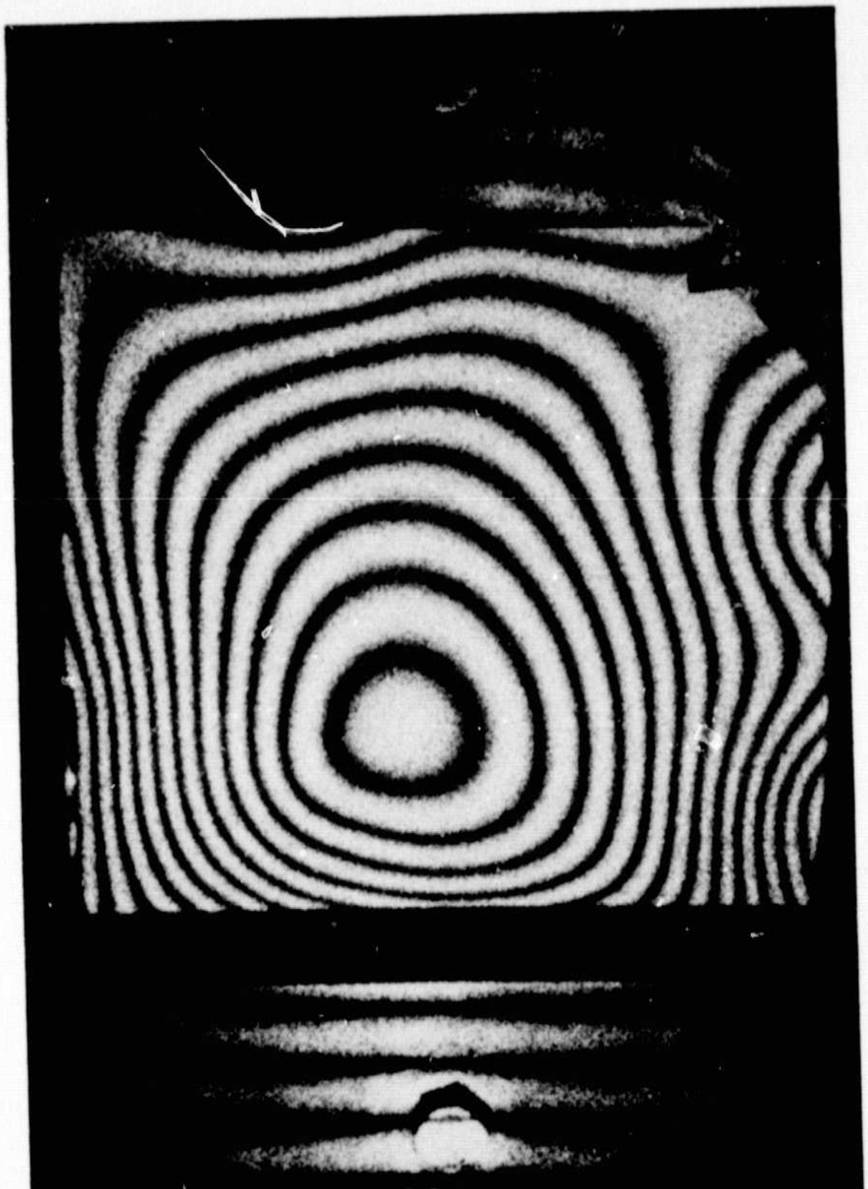
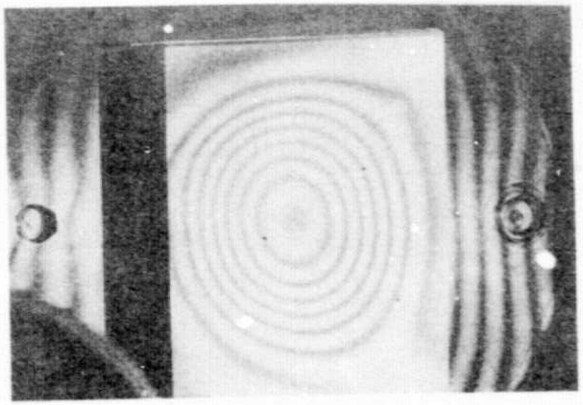
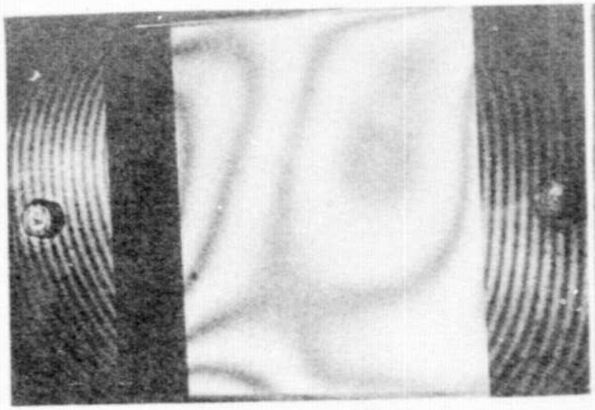


FIGURE 6. ALUMINUM SAMPLES

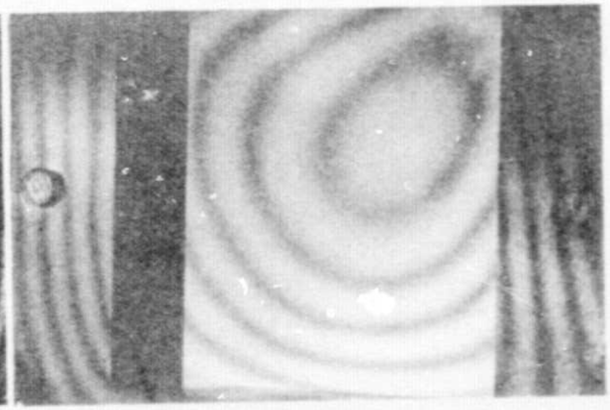
6 (a). Quarter Inch Hole



t = 0.0625"

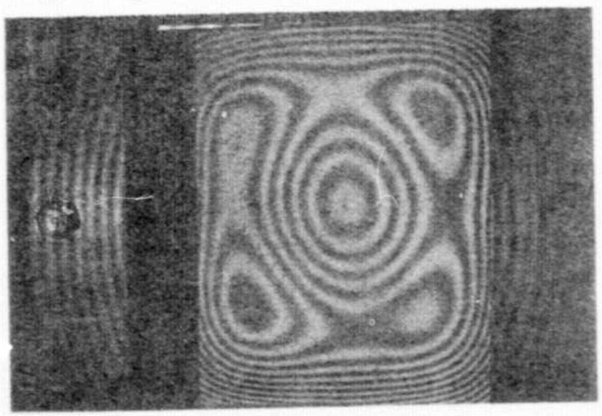


t = 0.193"

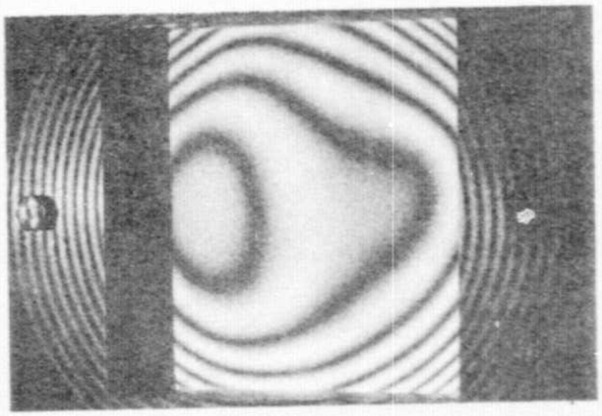


t = 0.315"

6 (b). Eighth Inch Hole

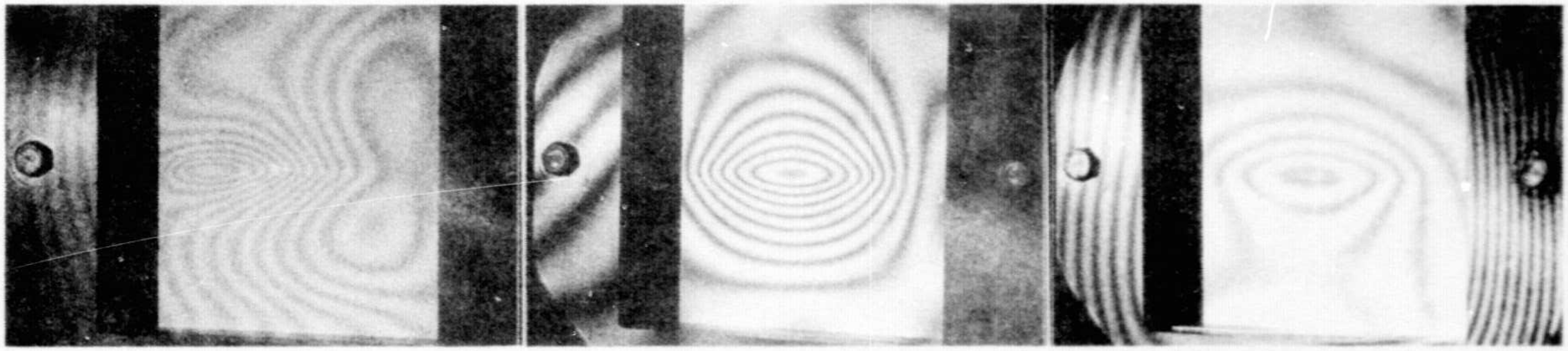


t = 0.0625"



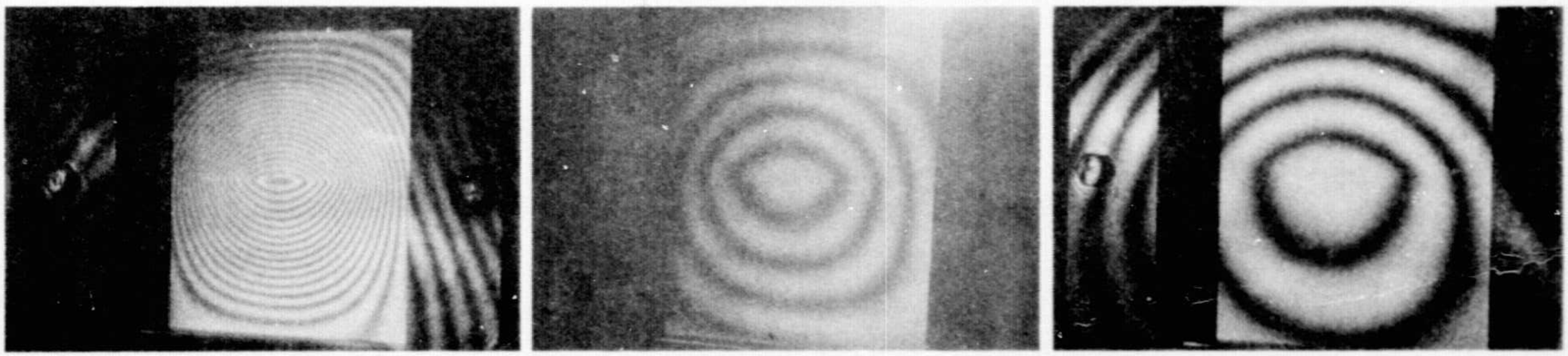
t = 0.193"

6 (c). Quarter Inch Groove



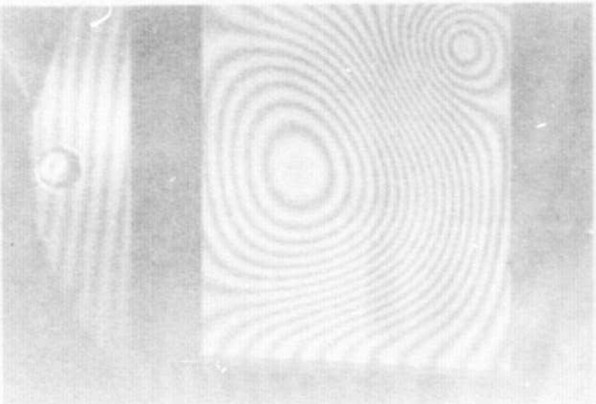
t = 0.0625"   t = 0.193"   t = 0.315"

6 (d). Eighth Inch Groove

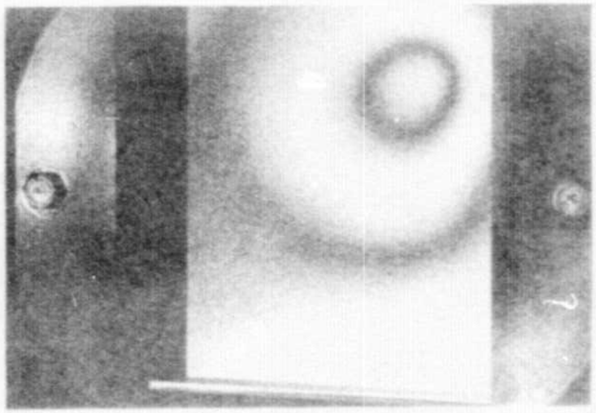


t = 0.0625"   t = 0.193"   t = 0.315"

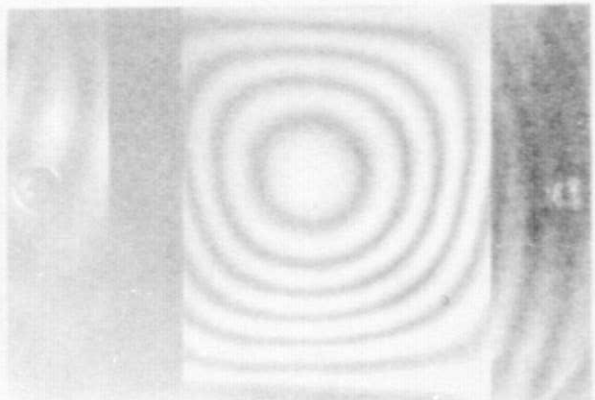
6 (e). Tape Roll



t = 0.0625"



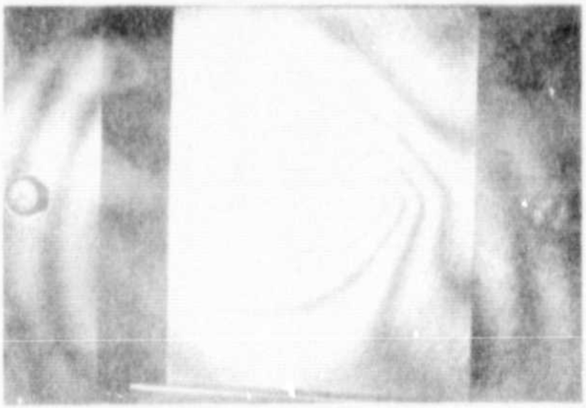
t = 0.193"



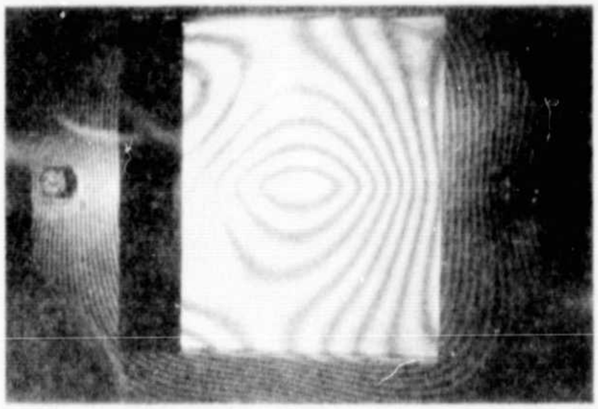
t = 0.315"

FIGURE 7. COPPER SAMPLES

7 (a). Quarter Inch Groove

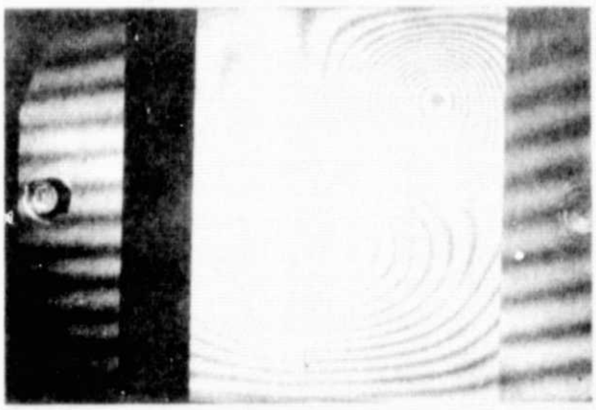


t = 0.0925"

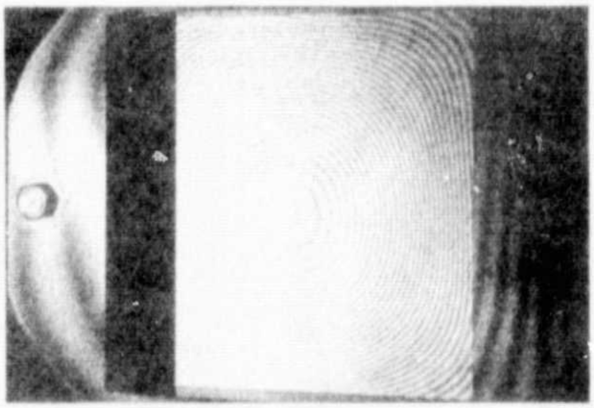


t = 0.250"

7 (b). Tape Roll



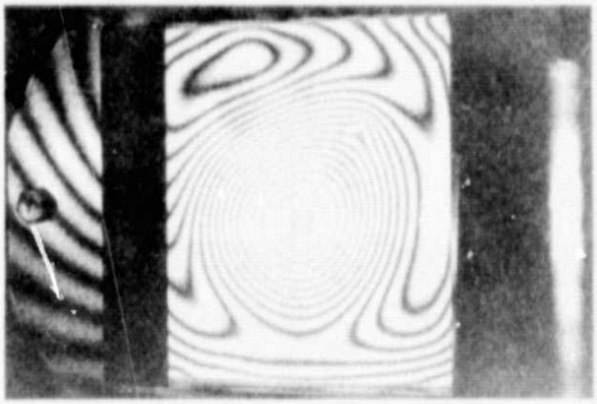
t = 0.0925"



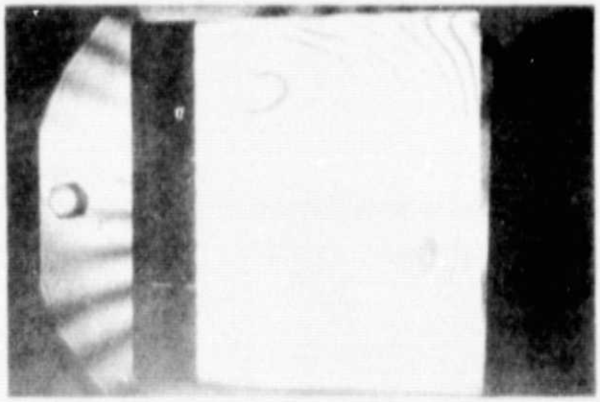
t = 0.250"

FIGURE 8. STEEL SAMPLES

8 (a). Quarter Inch Hole

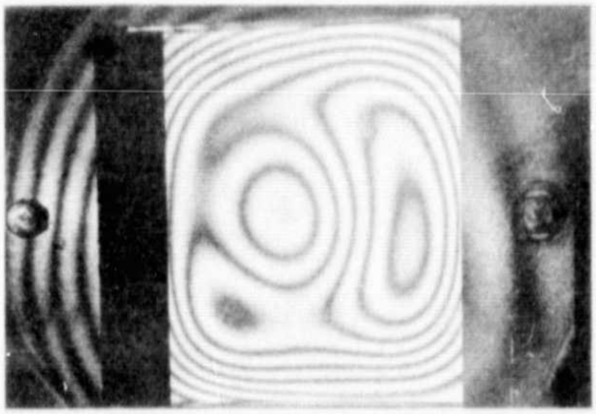


t = 0.055"



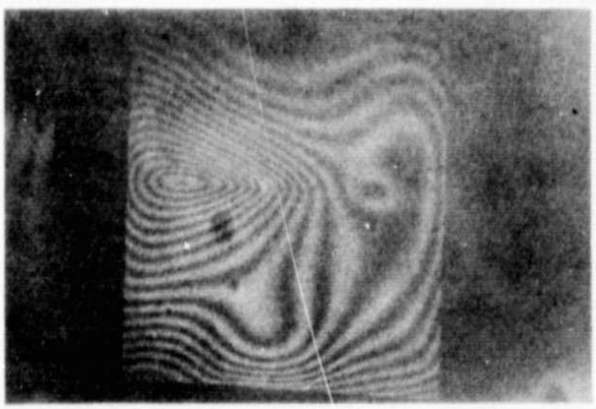
t = 0.196"

8 (b). Eighth Inch Hole

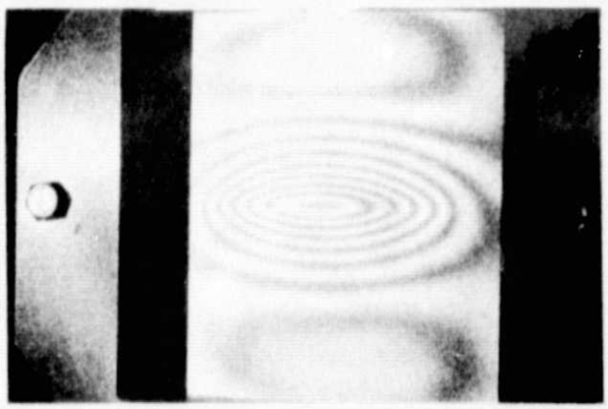


t = 0.055"

8 (c). Quarter Inch Groove

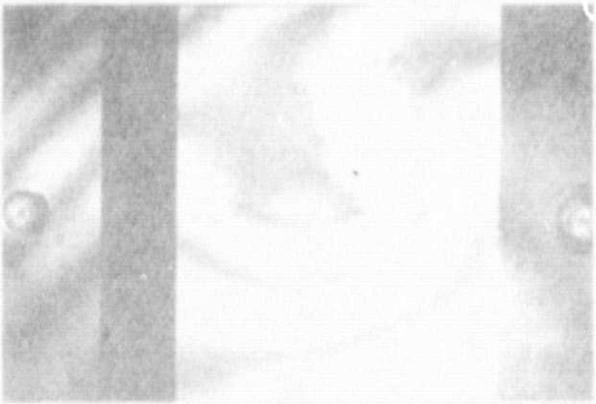


t = 0.055"



t = 0.196"

8 (d). **Eighth Inch Groove**



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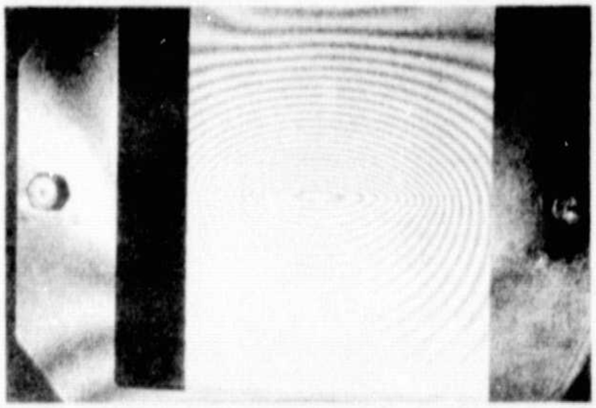
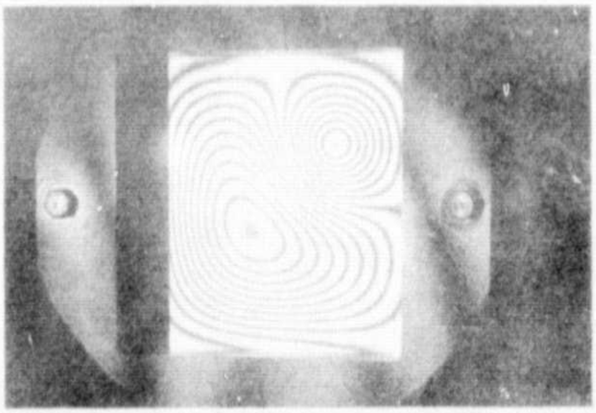
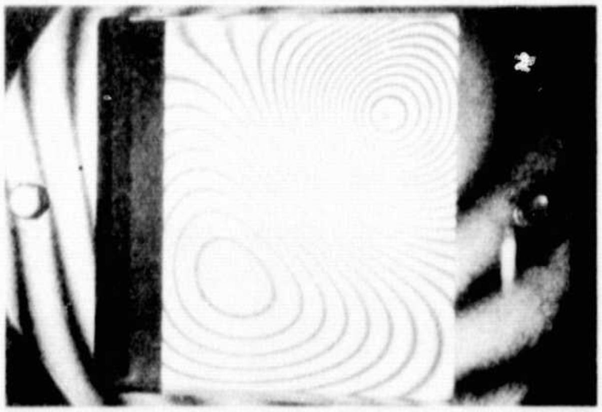


t = 0.196"

8 (e). **Tape Roll**



t = 0.055"



t = 0.196"

V. Conclusion

The techniques described in this report were successful in evidencing the prescribed flaws, but more work needs to be done to develop techniques which are more universally applicable. In particular, loading techniques should be developed which do not require pressurizing the samples and/or constraining the movement via a bezel or some such apparatus.